FREQUENCY HOPPING METHOD AND SYSTEM USING LAYERED CYCLIC PERMUTATION

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001]   The present invention generally relates to mobile radio communications. More specifically, the present invention relates to methods and systems for efficient and flexible use of the frequency spectrum available for communication in a mobile radio communication system.

RELATED ART

[0002]   Frequency hopping is a technique for ensuring that worst-case interference scenarios do not prevail for longer than one frequency hop interval, as opposed to the duration of an entire communication connection. Frequency hopping also provides frequency diversity, which combats fading experienced by slow moving mobile stations. Moreover, frequency hopping can also be used to eliminate the difficult task of frequency planning, which is of special importance in micro-cells. This can be achieved if all of the cells in a system use the same frequencies but each cell has a different hop

sequence. Such systems have been called Frequency Hopping Multiple Access (FHMA).

[0003]   In a frequency hopping systems each cell can use all of the available frequencies, but at different times, as determined by a pseudo-random frequency hop sequence generator. Such generators can be constructed either to yield a random probability that any two cells may choose the same frequency at the same time (known as non-orthogonal hopping), or to guarantee that specified cells or mobile stations never choose the same frequency at the same time (known as orthogonal hopping), or a mixture of the two techniques (e.g., signals in the same cell hop orthogonally, while being non-orthogonal relative to adjacent cell signals).

[0004]   A commercial example of a frequency hopping cellular radio system is the Global System for Mobile communications (GSM). The European GSM standard describes this system, which is based on a combination of time division multiple access (TDMA) in which a 4.6 *ms* time cycle on each frequency channel is divided into eight, 560 *μs* time slots occupied by different users, and frequency hopping in which the frequencies of each of the eight time slots are independent of one another and change every 4.6 *ms*.

[0005]   In a GSM system a channel is described by:

$$CH = SG(FN, MA, HSN, MAIO, TN),$$

where *SG* refers to the hopping sequence generator, *FN* the frame number, *MA* the pool of frequencies for mobile allocation, *HSN* the hopping sequence number, *MAIO* is the mobile allocation index offset and *TN* is the time slot

index. The pair (*HSN, MAIO*) defines a sequence assigned to channel *CH* for each time slot, and each frequency is given a unique number *MAI*, called a mobile allocation index. The output value of *SG* is a frequency; therefore, (*SG, TN*) is a *TDMA* physical channel. In *GSM, MA* has *N* elements, where $1 \le N \le 64$. Moreover,

$$HSN \in \{0, 1,...,63\}$$

$$MAIO \in \{0, 1,..., N-1\}$$

$$MAI \in \{0, 1,..., N-1\}.$$

Each channel on the time axis is identified with a frame number *FN*. That is, the channel occupies ever eight (8) time slots. As the frequency hopping changes frequency for each user from slot to slot, the time each hop takes is the duration of a frame and is equal to the indicated 4.6 *ms*.

[0006] The hopping sequence of GSM is pseudorandom and therefore its performance is constrained by the pool of available frequencies. In particular, because there are only a finite number of frequencies in the pool, there is repeated usage of the same frequency. The means by which the same frequency is scheduled to repeat within the GSM frequency hopping process is referred to as a sequence generator. Therefore, the sequence generator is not characterized by whether the same frequency repeats, but by how it repeats.

[0007] GSM was primarily designed to handle circuit switched voice traffic, and for such use, the pseudorandom hopping sequence used with GSM is sufficient. However, recently the need to support packet switching services has surfaced, which are characterized by bursty traffic. For

channel stability, bursty traffic requires high frequency diversity in a short time period.

[0008]   The current GSM frequency hopping sequence generator is based on randomizing the choice of frequencies from a finite pool of frequencies. Therefore, it is unavoidable to have bursty occurrence of the same frequency for a short period, if the frequency selection is random. Bursty occurrences of the same frequency along the hopping sequence compromises the desired effects of frequency hopping and, as such, compromises the diversity performance and reduces the error correction capability of the system.

SUMMARY OF THE INVENTION

[0009]   In order to reduce bursty occurrences of same frequencies during frequency hoping, a short term deterministic approach is used to achieve effective frequency hopping for services using packet switching. In particular, the present invention uses a Layered Cyclic Permutation (LCP) process/algorithm to increase efficiency for frequency hopping systems. The LCP process of the present invention uses vectorized sequences to achieve reduced bursty occurrences of the same frequencies during frequency hopping. The applicability of the LCP process according to the present invention is however not limited to frequency hopping. Instead, the LCP process according to the present invention applies generally to radio systems requiring scheduled resource allocation to achieve maximum usage diversity of the specific resource.

[0010]   Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]   The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein:

[0012]   Fig. 1 illustrates an exemplary cellular wireless network, such as a Global System for Mobile communication (GSM), using the frequency hopping LCP process according to the present invention; and

[0013]   Fig. 2 and 3 illustrate, in flowchart form, the LCP frequency sequence process according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014]   Fig. 1 illustrates an exemplary cellular wireless network, such as a global system for mobile communication (GSM), using the frequency hopping LCP process according to the present invention. The GSM system includes a public land mobile network/area/system (PLMN) 10, which is

composed of a plurality of areas 20, each with a mobile switching center (MSC) 30 and an integrated visitor location register (VLR) 40. The areas 20, in turn, include a plurality of location areas (LA) 50, which are defined as part of a given area 20 in which a mobile station (MS) 60 may move freely without having to send update location information to the area 20 that controls the LA 50. Each LA 50 is divided into a number of cells 70. The mobile station (MS) 60 is the physical equipment (e.g., a car phone or other portable phone, used by mobile subscribers to communicate with the cellular network 10, each other, and users outside the subscribed network, both wire-line and wireless).

[0015]   The MSC 30 is in communication with at least one base station controller (BSC) 80. The BSC 80 is in contact with at least one base transceiver station (BTS) 90. The BTS 90 is the physical equipment, illustrated for simplicity as a radio tower, that provides radio coverage to the geographical part of the cell 70 for which it is responsible. It should be understood that the BTS 90 may be connected to several base transceiver stations 90 and may be implemented as a stand-alone node or integrated with the MSC 30. In either event, the BSC 80 and the BTS 90 components, collectively, are generally referred to as a base station system (BSS) 100.

[0016]   The area 10 includes a home location register (HLR) 110, which is a database maintaining all the subscriber information, e.g., user profiles, current location information, international mobile subscriber identity (IMSI) numbers, and other administrative information. The HLR 110 may be a co-

located with a given MSC 30, integrated with the MSC 30, or alternatively can service multiple MSCs 30, the latter of which is illustrated in Fig. 1.

[0017]   The VLR 40 is a database containing information about all of the mobile stations 60 currently located within the area 20. If an MS 60 roams into a new area 20, the VLR 40 connected to that MSC 30 will request data about the MS 60 from the HLR database 110 (simultaneously informing the HLR 150 about the current location of the MS 125). Accordingly, if the user of the MS 60 then wants to make a call, the local VLR 40 will have the requisite identification information without having to re-interrogate the HLR 110. In the aforedescribed manner, the VLR and HLR databases 40 and 110, respectively, contain various subscriber information associated with a given MS 60.

[0018]   Each MS 60 is affected by a myriad of signal-degrading phenomena. For instance, small-scale fading (also called multipath, fast or Rayleigh fading) creates peaks and valleys in received signal strength when the transmitted signal propagates through populated areas with signal-reflecting structures. A second-degrading phenomena, large scale fading (also called log-normal fading or shadowing), reduces received signal strength when the transmitted signal is degraded by large objects (e.g., hills, building clusters, force, etc.). A third signal degrading phenomena, co-channel interference, reduces the ability of an MS 60 to correctly receive a desired signal from a first BTS 90 because an undesired signal from a second, more distant, BTS 90 is interfering. Many other signal degrading

phenomena (e.g., path loss, time dispersion, and adjacent channel interference) adversely impact wireless communications.

[0019]   The frequency hopping process and system according to the present invention advantageously combats signal-degrading phenomena. The frequency hopping process according to the present invention is preferably implemented in combination with an MS 60 and a BTS 90, and more generally within a wireless network system such as that shown in Fig. 1. Furthermore, as is well known, the frequency hopping process of the present invention may be implemented in a cell transceiver (TRX) responsible for the Broadcast Control Channel (BCCH). However, it is readily apparent to those skilled in the art that the frequency hopping process and system according the present invention is not limited to the wireless system shown in Fig. 1. Such has been used by way of illustration only.

[0020]   Fig. 2 and 3 illustrate, in flowchart form, the LCP frequency sequencing process according to the present invention. The LCP frequency sequencing process is also discussed hereinafter.

[0021]   According to the present invention, LCP sequences are generated using two steps:

1.   Generate a finite sequence of size n, where n is the number of available frequencies.

2.   Generate an infinite sequence using the finite sequence generated in the first step.

[0022]   As is seen in Fig. 2, the LCP process requires input of a specific number of frequencies n (*MA* in GSM) along with a desired sequence length m (S100). Once this information is known, the process can be continued in two alternative ways. When n is a product of mutual prime numbers, represented by q and p, case one (1) is followed in the flowchart illustrated in Fig. 2 (S110). Alternatively, when n is not a product of mutual prime numbers, but is even, case two (2) is followed in the flowchart illustrated in Fig. 2. In terms of the sequences generated, both cases (1 and 2) are equivalent.

[0023]   The LCP process according to the present invention generates an LCP sequence with the frequencies n for two specific cases. In particular, case 1 where n is a product of two mutual prime number q and p (S120), and case 2 where n is even, i.e. $q=2$ and $p=n/2$ (S120).

[0024]   After input of an initial vector of frequency indices and initialization (S140 and S150), a finite sequence is generated based upon the determination in a previous step (S110). In particular, if case 1 (S120), let $a_l^{(k)}$ indicate the index of frequencies to hop at a time k for a channel l (S160). For both cases, l can be expressed by (i, j) such that $l = i \cdot q + j$, where $n = pq$. Starting with $a_l^{(0)} = a_l$ for $l=0,1,2,..,n-1$, the value of $a_l^{(k)}$ at the time k is determined by

$$a_l^{(k)} = a_{l_k}$$

where l_k is a function of k and l, and is determined through (i, j) by

$$l_k = \left[(i + k_1) \bmod p\right] \cdot q + \left(j + k_2\right) \bmod q$$

with $i = 0,1,\ldots,p\text{-}1$ and $j=0,1,\ldots,q\text{-}1$ (S170).

For case 1:

$$k_1 = k_2 = k. \text{ (S180)}$$

For case 2:

$$k_1 = \left[(k \bmod 2)(k+1)/2 + (1 - k \bmod 2)k/2\right] \bmod n .$$

$$k_2 = \left[(1 - k \bmod 2)k/2 + (k \bmod 2)(k-1)/2\right] \bmod n \text{ (S190)}.$$

[0025]   The additional steps illustrated in the flowchart of Fig. 1 are self-explanatory (S2000 – S2300), where S2300 connects the process illustrated in Fig. 2.

[0026]   Table 1 shows an example for $n=6$. Since $n=2\cdot3$ is a decomposition into two mutual prime numbers as well as an even number, both case 1 and case 2 apply.

Table 1

Case 1						
l=0,1,2,..,5						(k)
3	2	5	4	1	0	(1)
4	5	0	1	2	3	(2)

1	0	3	2	5	4	(3)
2	3	4	5	0	1	(4)
5	4	1	0	3	2	(5)
0	1	2	3	4	5	(6)

Case 2						
l=0,1,2,3,5						(k)
1	0	3	2	5	4	(1)
2	3	4	5	0	1	(2)

5	4	1	0	3	2	(3)
0	1	2	3	4	5	(4)
3	2	5	4	1	0	(5)
4	5	0	1	2	3	(6)

[0027]   In Table 1, total blocks for n = 6, with an initial value x = {0,1,2,3,4,5}, and l refers to channels (row) and (k) refers to time (column).

[0028]   The LCP process for generating an infinite sequence is illustrated in flowchart form in Fig. 3. Input is a square matrix with n rows and n columns, and is obtained from the results of the LCP process shown in Fig. 2 (S200). Alternatively, the input is a set of initial vectors with a specific selection scheme, or a random number generator (S210). If the input is from S200, a repetition distance r is set (S220). The repetition distance r is defined as the minimum number of hops between two occurrences of the same frequency in a sequence. It is readily seen that cyclic hopping in GSM (HSN = 0) provides a maximum repetition distance n – 1 when there are n frequencies in the pool (MA = n).

[0029]   Regardless of input, a starting point in the n by n matrix is set. In particular, a time index of k = 0 and an initial vector (x_1 for S210) are used (S230). Next, the type of scheme is determined. Specifically, the data input in steps S200 and S210 is considered and a decision as to how to proceed in the process is made (S240). If input from S210 contains neither

b) nor c) then the process flow continues to S250. Here, an initial vector from the input matrix is determined, and a number i, where $n - r \le i \le n$, is generated. The number i is then input into function

$$a_I^{((i+k)\bmod n)} \text{ (S260).}$$

Next, an n by n matrix is generated (S270).

[0030] Based upon the scheme, it is possible to generate a random number i, where $0 < i \le v$ (S280). Then, using the set X from S210, an initial vector x_i is selected (S290). The process then proceeds to S270, discussed hereinabove.

[0031] In addition to the above, based upon the scheme, an initial vector from the input matrix may be determined, and a number i, where $0 < i \le v$, is generated (S300). Following this step, S290 is processed. Regardless of the step chosen after decision block S240, the steps that occur thereafter ultimately lead to decision block S310. At S310, either the process illustrated in Fig. 3 is stopped, or the time variable k is incremented (S320) and the process of Fig. 3 is repeated.

[0032] Given a block (or matrix) $\left\{a_I^{(k)}\right\}_{I=0,k=0}^{n,n}$ generated using the process illustrated by the flowchart of Fig. 1, an infinite sequence can be generated block-wise, block-wise with a length n. The blocks can be chosen by random selection of the initial vector

$$x = \left\{a_0^{(0)}, a_1^{(0)}, \ldots, a_{n-1}^{(0)}\right\}$$

from $n!$ possible values, or simply by repetition of the same block via

$$s_l^{(t)} = a_l^{(k)} \; for \; k = t \bmod n$$

which has repetition distance n-1 and period n.

For sequences with longer periods

$$s_l^{(k)} = a_l^{(k+i)\bmod} , i \cdot n \leq k < (i+1) \cdot n$$

for i=0,1,2,..,n-1-r, may be deployed, where r is a given repetition distance ,k is the index for n by n blocks, and the symbol "mod" refers to the modulo operation. Using this method of extension of blocks, a time sequence $\{s_l(t)\}_{t=0}^{\infty}$ with repetition distance $r < n - 1$ can be generated which has a period $(n-r)n^2$.

[0033]   The mechanism underlying LCP is group operation rather than random selection (GSM FH). The sequences generated by LCP can be better understood if seen in block (matrix) form instead of an independent single sequence. As block, the LCP sequences have the following properties:

- A basic block for the LCP sequence is matrix $\{s_{i,j}\}$ of n by n, where the column index i indicates the time and the row index j indicates different sequences.

- A sequence is generated block-wise, and each block is an n by n matrix.

- No two columns are equal, i.e. $S_{i,j} \neq S_{i',j}$ *for* $i \neq i'$ and no two rows are equal, i.e. $S_{i,j} \neq S_{i,j'}$ *for* $j \neq j'$. Consider the rows as channels, then no channel remains fixed when time advances in column. Consider columns as sequences, then no two sequences contain the same frequency at the same time.

- Within the n x n matrix, each frequency occurs only once in a sequence, i.e. the distance of repetition is n-1.

- In the case of $p=1$ or $q=1$, the sequences generated are mutually offset cyclic sequences (corresponding to HSN=0 in GSM).

- Sequences generated using different initial vectors are independent.

- By repeating the block consecutively, a periodic sequence with repetition distance 2·lcm(p,q)-1 is achieved, where lcm refers to the least common multiple.

Table 2

x={0,1,2,3,4,5}						
l=0,1,2,3,4,5						(k)
3	2	5	4	1	0	(1)
4	5	0	1	2	3	(2)
1	0	3	2	5	4	(3)
2	3	4	5	0	1	(4)
5	4	1	0	3	2	(5)
0	1	2	3	4	5	(6)

x={1,2,3,4,5,0}						
l=0,1,2,3,4,5						(k)
4	3	0	5	2	1	(1)
5	0	1	2	3	4	(2)
2	1	4	3	0	5	(3)
3	4	5	0	1	2	(4)
0	5	2	1	4	3	(5)
1	2	3	4	5	0	(6)

x={2,1,4,3,0,5}						
l=0,1,2,3,4,5						(k)
3	4	5	0	1	2	(1)
0	5	2	1	4	3	(2)
1	2	3	4	5	0	(3)
4	3	0	5	2	1	(4)
5	0	1	2	3	4	(5)
2	1	4	3	0	5	(6)

x={0,3,2,5,4,1}						
l=0,1,2,3,4,5						(k)
5	2	1	4	3	0	(1)
4	1	0	3	2	5	(2)
3	0	5	2	1	4	(3)
2	5	4	1	0	3	(4)
1	4	3	0	5	2	(5)
0	3	2	5	4	1	(6)

[0034]   Table 2 illustrates several frequency sequences where $n=6$ with $(q,p)=(2,3)$. The sequences were generated under case 1 of the present invention.

[0035]   The number of frequencies available for GSM is 64. To determine feasibility of the present invention, it is useful to find out how many $n \leq 64$ frequencies exist that allow the process of the present invention to achieve the maximum repetition distance $n - 1$. Here, the trivial case of prime numbers is excluded from discussion, because prime numbers enable cyclic sequences only, albeit with repetition distance $n - 1$ (known). In can be proven using group theory that the maximum repetition distance $n-1$ can be achieved when $n=pq$, with p and q being mutual prime, or at least when n is even. Using this result to analyze non-prime numbers $n \leq 64$ with respect to the possible decomposition, it turns out there are only two numbers by which the maximum repetition distance cannot be achieved with the LCP process of the present invention, and they are $n=9$ (LCP yields a sequence with repetition distance 5, while the maximum is 8) and $n=25$ (LCP yields a sequence with repetition distance 9, while the maximum is 24). Therefore, the conclusion can be drawn that the algorithm would not achieve repetition distance $n-1$ for $n=9$ and $n=25$. Further feasibility and statistical information can be found in the Appendix, document "Frequency Hopping with LCD Sequences" by David D. Huo, the entire contents thereof being incorporated by reference.

[0036]   The maximum repetition distance is not achieved at the cost of interference diversity. The LCP sequences generated by different initial vectors are independent, meaning their collision probability is no more than two statistically random sequences. In practice, for n frequencies there are $n!$ initial vectors to chose from.

[0037]   As already mentioned hereinabove, the initial vectors can be chosen deterministically as well as randomly.   For a given repetition distance, a random selection of initial vectors from a designated pool of initial vectors can provide a block-wise pseudorandom sequence.   Therefore, the sequence is generated in block (matrix) form and the randomization takes place among the different initial vectors.

[0038]   Referring now to Fig. 3 once again, v initial vectors (out of $n!$) are determined and put into a pool X (S210).   During frequency hopping, a random number i, with $1 \leq i \leq v$, is generated each n time units, and an initial vector x_i out of the set X is selected (S280-S290).   The vector is used to generate a basic block, i.e. an n by n matrix (S270).   The random number i is generated by a conventional random number generator.   The selection of the pool of the initial vectors X is subject to the consideration of repetition distance, or other system/network requirements.

[0039]   The deterministic selection of blocks can be done in many different ways.   One such selection process is presented herein using the extension of basic blocks in Fig. 3 (scheme 3) according the present invention.   However, other possible deterministic (scheduling) approaches, not explicitly discussed herein, are fully embraced by the spirit of the present invention.   Therefore, a detailed discussion of such is not required.

[0040]   The invention being thus described, it will be obvious that the same may be varied in many ways.   Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such

modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.